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Tianfeng Wan

# **The Tectonics of China**

**Data, Maps and Evolution**

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**Data, Maps and Evolution**

With 156 figures, 52 of them in color



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linear structural system; parallel structural system; longitudinal structural system; frame structure system, etc.). However, this classification will not be used in the following chapters.

Most recent monographs and textbooks on tectonics (e.g. Currier, 1992, 1993; Kearney and Yin, 1994; Van der Plighe and Marsh, 1994; Doores, 2001; Brackley, 2011) used the same tectonic models: convergent tectonics (subduction, collision, indentation) and mass belts; Divergent tectonics (oceanic ridges, rifts, extension, basins, detachment) and metamorphic zone complexes; transform tectonics (transform and strike-slip faults); Inversion tectonics (active or earlier tectonic systems). The theoretical system emphasizes the mechanism and the components of each tectonic model, and is easy to be understood. However, this system does not place much emphasis on tectonic history. The system emphasizes the tectonic analysis of specific geological situations, but it is important to realize that geological sciences is essentially a historical science, and that many changes and many different tectonic events have affected the lithosphere from more than four billion years of Earth history.

It is not the intention for us to repeat the methods of tectonic analysis. However, only emphasizing the methods but never discussing the tectonic evolution in detail, as McWitt (1992) did, has been proved ineffective.

Many monographs and papers emphasize the historical aspects of the tectonics of China have been published by Lin (1971, 1981, 1984, 1986, 1987, 1988, 1989), Liu (1981, 1982, 1983, 1984), Wang (1981, 1982, 1983, 1984), Ren (1981, 1982, 1983, 1984), 2003) and Khan and He (1981, 1982).

Here such as the concerned with "Historical Tectonics". On one hand, specialists engaged in historical tectonics pay more attention to structure type and the characteristics of geological formations and their origins, and analyze their lithological and paleogeographic characteristics, their geographic environments of formation and the origins of the sedimentary sequences, with emphasis on their historical evolution. On the other hand, tectonic modelers pay more attention to the transformation of rock bodies, the rock deformation, structural geometry, the stress and strain states, the habitats on the mechanism of deformation. Although most researches engaged in tectonics agree that both geological formation and transformation should be studied, and that historical and mechanical analyses should be combined, due to the deficiencies of the long experience and the focus of their interests, these different approaches may have occurred naturally. Zhong WY (1979, 1984) and Li (1991, 1993) indicated that these approaches should be integrated in the study of the tectonics of China. The author considered that it is really important for geological science precedents in the present volume, though it is very difficult.

In this book, the author does his utmost to combine the studies of formation and transformation using the plate tectonic theory, together with historical and mechanical analyses. Abundant and recently reported geological, geochronological and geophysical research data are utilized to describe and discuss the sequence of tectonic events which have affected the Chinese continental lithosphere from the Archean to the Recent. Until the present time, it is difficult to achieve this aim because of the scarcity of data on the tectonic evolution.

In this volume, for understanding the tectonics of China, the author puts forward many new views: calculation of the thickness of the continental crust on the Sino-Korean plate and the Arabian and Afro-Eurasian plates; determination of the velocity during motion the Supercontinent of Rodinia by sea level and the continental blocks were amalgamated to form the Chinese continent, establishing the plates during the Mesozoic; the 45°E-45°W lines were deformed on the Sino-Korean and Yanzagui plates respectively following the changes of the meridional and longitudinal distribution of the Chinese continental blocks during the Paleozoic. During the Late Paleozoic, most of the continental blocks were reorganized into a single China block and were connected with the Eurasian Plate. Subsequently China continent was affected by intra plate deformation with three series of shortening in a north-southward and E-W direction Period (260-230 Ma); Sichuan Plate Period (220-200 Ma); Hainan Plate Period (140-130 Ma); two periods of shortening with a north-southward Plate Period (120-105 Ma); North-South-South Period (90-25 Ma). Since 100 Ma (Quaternary Period), the state of stress among the plates which constitute the Chinese continent has been nearly in equilibrium.

In this volume, the characteristics of many collision zones in the Chinese continent are analyzed in detail and discussed. The type of the thickness of the crust and the lithosphere beneath

is proposed for the "main body" of the *U-hat* sphere beyond the eastern Asia continent, which is possibly induced by the counterbalancing radiation of the continental crust extension to the sea onto oceanic mantle. The origin of the environment by radiation is recognized; the influence of crustal extension on duress of the Mesozoic Cretaceous on periods of neotectonic revolution in China is made understandable; the two hypotheses about the dynamic mechanism that control global tectonics are evaluated.

This book was originally written by the author in Chinese and published by the Geotectonic Publishing House in Heilongjiang in 2014. After incorporating many specific comments, the book was translated into English, with a reduction of local terms and the removal of discussions which were not necessary to the foreign readers. Through translation, emphasis has been placed on areas such as features and the major tectonic zones which have affected the Chinese continent. A new series of preliminary maps have been prepared following the suggestions of experts in specified fields. For the sake of the foreign readers, the articles and long titles of critical features have been translated. Original data are recorded in Appendices, and a large number of references are cited, particularly from the Chinese literature, to facilitate further research in Chinese literature.

Hanfeng Wang  
Jiayu Qu (June 2014)

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Although the preparation of this book is the responsibility of the author, it clearly represents the collective literature and scientific creation of many researchers, colleagues and friends. I would like to express my heartfelt gratitude for their invaluable help and guidance.

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## Chapter 1 Introduction

Tectonics is a comprehensive subject area involved in Earth sciences concerning the historical development, evolution and origin of the earth. The aims of this subject are to determine the composition, the structure, the movements (tectonic deformation and displacement) and the evolution of the inner sphere of the solid earth, the lithosphere, and its relationship to activity in the interior, in the lower mantle and the core. This subject area is encompassed in the Theory of Plate Tectonics originating from the investigation of the ocean floor's structure, and combined with the theory of continental tectonics which until then had not universally accepted, evolved into a comprehensive theory of global tectonics (Kennedy

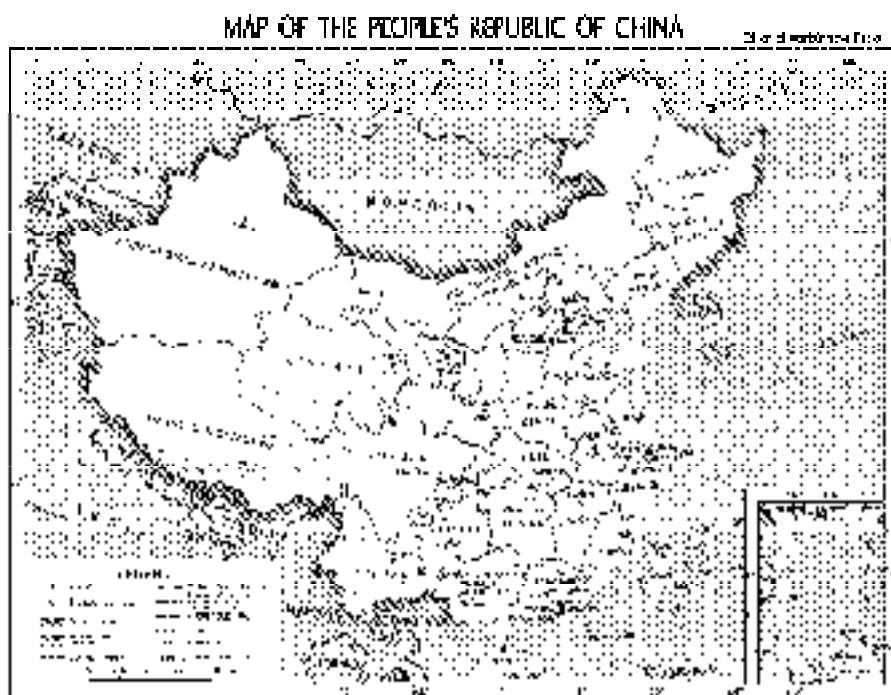


Fig. 1.1 Geological map of the People's Republic of China, with annotation of tectonic zones (Springer-Verlag, Beijing, China).

from all branches of the geology, geophysics, and geochemistry, including isotope geochemistry, mineralogy, stratigraphical paleontology, micropalaeontology, micromineralogy and micropetrology contribute to the

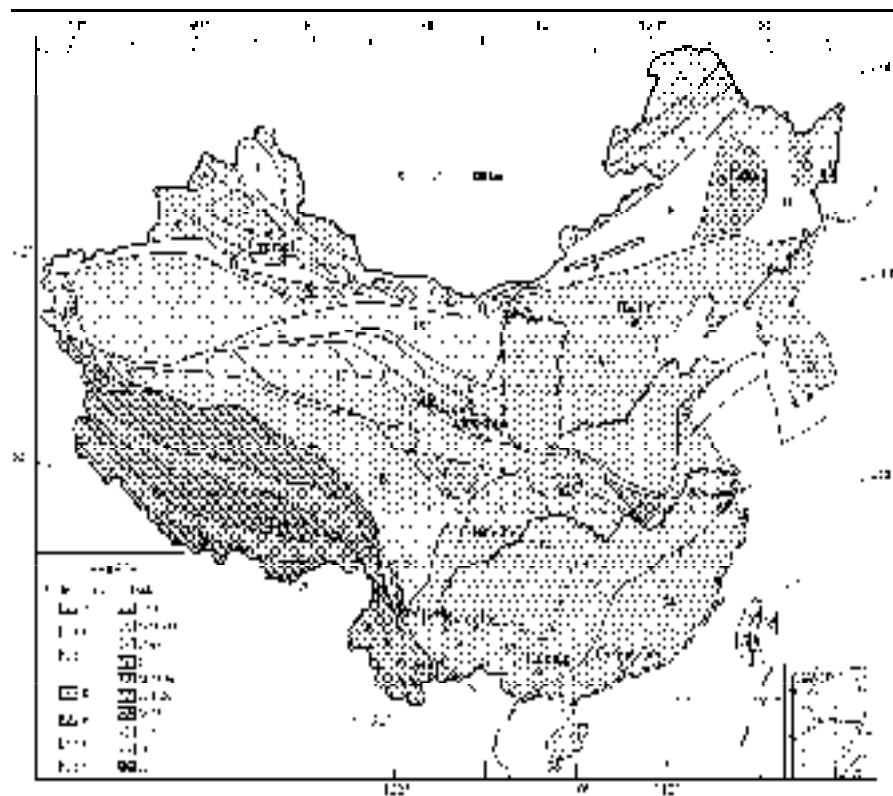


Fig. 12. Tectonic zones of China during the Palaeozoic.

blocks in the Palaeozoic: (1) North China Craton; (2) South China Craton; (3) North China Craton; (4) North China Craton; (5) North China Craton; (6) North China Craton; (7) North China Craton; (8) North China Craton; (9) North China Craton; (10) North China Craton; (11) North China Craton; (12) North China Craton.

blocks in the Palaeozoic: (1) North China Craton; (2) South China Craton; (3) North China Craton; (4) North China Craton; (5) North China Craton; (6) North China Craton; (7) North China Craton; (8) North China Craton; (9) North China Craton; (10) North China Craton; (11) North China Craton; (12) North China Craton.

blocks in the Palaeozoic: (1) North China Craton; (2) South China Craton; (3) North China Craton; (4) North China Craton; (5) North China Craton; (6) North China Craton; (7) North China Craton; (8) North China Craton; (9) North China Craton; (10) North China Craton; (11) North China Craton; (12) North China Craton.

blocks in the Palaeozoic: (1) North China Craton; (2) South China Craton; (3) North China Craton; (4) North China Craton; (5) North China Craton; (6) North China Craton; (7) North China Craton; (8) North China Craton; (9) North China Craton; (10) North China Craton; (11) North China Craton; (12) North China Craton.

development of this subject area, encourage the cooperation of specialists involved in all the geoscience disciplines in the construction of a comprehensive Earth Sciences system.

In this book, the tectonics of China (Figs. 1.1 and 1.2) is dealt with as a sequence of tectonic events through geologic caltime. A comprehensive analysis of these events is based on the interpretation of records preserved in the rocks, which provides the evidence of the deformation produced by the movement of continental blocks during processes of the subduction, collision and finally convergence or the extension.

The tectonic systems developed due to these events are described in terms of rates of movement, orientation of tectonic stresses, major tectonic stress, and the nature and type of deformation. These tectonic and structural aspects are interpreted, together with the tectonic sedimentary, tectonic paleogeography and tectonic geomorphology, in the distribution of continental blocks and tectonic geological periods based on paleogeomorphology and deformation of paleogeographic units data. As far as possible, these aspects are dealt with in a quantitative and a purely qualitative manner.

The Chinese continent is located in Eastern Asia (Fig. 1.1), composed of the Qinshui-Kangursi-Habei Plateau, the Inner-Mongolia-Urdas-Yunnan-Guizhou Plateau, the Dabai-Hangai and Inner-Tibet Plateau and their surrounding mountains, and the eastern plains and hills. Generally, the Chinese continent consists of large continental craton and small blocks, which were gradually amalgamated to form the present Chinese continent. Unlike the Paleozoic-ozo tectonic blocks had been identified in the Chinese continent (Fig. 1.2) had been divided into five tectonic domains, which will be discussed in detail in later chapters. The evolution of the Chinese continent was very different from the evolution of the North American, South American, Eurasian, African and Australian continental plates.

## 1.1. Tectonic Events

**Concept:** Before discussing tectonic events it is necessary to introduce the concept of the tectonic stratigraphic unit (or period), a term first proposed by geologists of the Soviet Union in the 1940s and introduced in the study of the tectonics of China by Zhang RY (1969). American geologists have also used a similar concept, the "tectonostratigraphic unit" more recently (Blümlberger and Harvey, 1996).

A tectono-stratigraphic unit encompasses all the tectono-stratigraphic features of a tectonic unit, distinctively by a particular type of deformation developed due to a particular tectonic series. In terms of time, a tectono-stratigraphic unit represents a period in the tectonic evolution of the earth's surface in space in covers the area affected by a specific tectonic event (Fig. 1.2).

The boundary of a tectono-stratigraphic unit is taken as a base of the sedimentation, marked by a regional angular unconformity which separates two tectono-stratigraphic units (Fig. 1.3). The tectono-stratigraphic unit lies between two angular regional unconformities. An angular regional unconformity is formed when an older rock unit deformed by either compressive or extensional is then uplifted, eroded and buried by younger rocks. The boundaries of tectono-stratigraphic unit should not be taken as parallel unconformities or disconformities, as these do not represent significant tectonic events.

Different tectono-stratigraphic units are characterized by different rates, styles and degrees of rock deformation, with different intensity, resulting from different stress orientations in different tectonic environments (Fig. 1.4). The geochronologic time occupied by a tectono-stratigraphic unit is a "tectonic period". Each tectonic period can be divided into a stable (or "quiescent") period, which lasted for a relatively long series of time, and an active (or "catastrophic") period which occupied a much shorter period of time at the end of the tectonic series (Table 1.1). Each tectonic series commences with a long and stable period and ends with a short and active period. Movement of blocks, rock deformation and the related metamorphism and magmatism mainly constitute a tectonic event over the shorter and active tectonic period. By convention, these tectonic events are named after the area in which the tectono-stratigraphic unit first occurs used. However, for these events are named after their neotectonic or geomorphic evolution

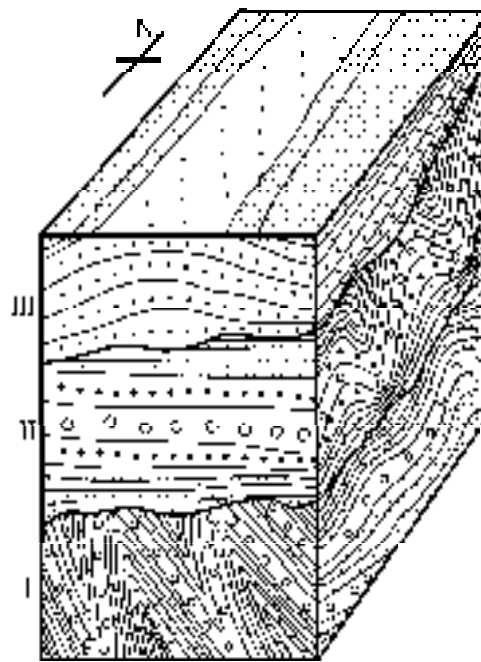


Fig. 1.5. Three-stage tectonic evolution of a continental shelf and different types of tectonic structures

I. Erosion of a continental shelf, development of a tectonic structure of a continental shelf with a thick sedimentary layer and a basement of crystalline rocks. II. Erosion of a continental shelf, development of a tectonic structure of a continental shelf with a thin sedimentary layer and a basement of crystalline rocks.

II. Transition of a continental shelf to a tectonic structure of a continental shelf with a thin sedimentary layer.

III. Erosion of a continental shelf, development of a tectonic structure of a continental shelf with a thin sedimentary layer.

interfacial comparison becomes easier. Conventional terms, derived from local tectonic periods or local events, are therefore used as far as possible in this book.

The degree and style of tectonism are different in the active and passive periods, but there is usually some connection and dependence, for example, the orientation of tectonic stresses and the direction of plate movement may be the same in both periods. However, the styles and rates of rock deformation are very different and the mass index of the stresses are different and the types of magmatic activity and metamorphism are also different (Table 1.1).

## 1.7 Universal Tectonic Periods

Smith (1836–1866) proposed that there was a rhythm in the tectonic evolution of the Earth and that geological history was characterized by successive "series" (collectively "tectonic phases") which occurred at the same time in different parts of the world. In the 20th century this principle exerted a great influence on the development of tectonics. It has been used continually and reverse since it was first put forward. The German-Soviet structural geologist A. I. Arkharov considered that rock deformation increased dramatically with changes in the tectonic regime (Arkharov, 1964), and some American geologists (e.g. Gilluly, 1949) even distinguished between the concept of phases of universal orogeny, but





and their destruction at subduction zones along the margins of the oceans, it could easily be assumed that the processes of subduction and collision were also continuous processes. However, Linné (1989) and Bengtson (1992) hypotheses considered many disjunct tectonic roots before 1990's. When the much more detailed third edition of the tectonic-analytical map was published at the end of the 1990's (Güncör et al., 1999; Güncör and Koca, 1992; Völz et al., 1996), analysis showed that since the White Cliffs event (1500 Ma) the tectonic plates and oceans had all expanded during the same six periods, with movements in different directions and at different velocities (Table 1.2) (Fig. 1.4). Sea floor spreading at velocities of several cm/y shows that the earth has the properties of a neo-plastic solid, while the processes at subduction zones seem to run with dimensions are in some extent connected with general continental expansion and contraction elements of periodicity.

Evidence compiled in this volume shows that the tectonic evolution of the earth has not become linear with a uniform rate of change, but non-linear with periodic variations in the rate of change. The only present evidence it appears that the processes continue over a period of time at a more or less constant rate, but are then interrupted by sudden and catastrophic changes. Such qualitative and quantitative changes are characteristic of all evolutionary processes. As in Güncör (2013) has explained previously, like all other geological processes, they can be considered in terms of non-linear continua in a probabilistic state. The evolution of the Earth seems to than be studied in the dark sleep of "chaos" theory.

In the past two hundred years, there has been a lively theoretical debate between proponents of minor and major tectonic and geological processes have continued in much the same way and at the same rate in response to geological time (Linné, 1989; Volz, 1996) and proponents of catastrophism who believe that geological processes proceed by infrequent but catastrophic events (Linné et al., 1992). At present, most of the scientific force that wise concerns can be reconciled. It is recognized that there are such periods for periods of infrequency last for several long time span, which is the time with derive for catastrophic events, occupies a much shorter time span (Linné et al., 1992) tectonic events represent this catastrophic period (Table 1.1).

Tectonic events are if they can resolve as their complete history is rarely presented in the geological record. The evidence is never complete, shows deformation, block displacement, vicarous tectonism and large scale uplift of the Earth's surface have resulted in widespread erosion, forming unconformities where the geological record has been destroyed. For this reason the study of tectonics did not advance very rapidly in many years of the world. In many areas, facts are few, tectonic and geodynamic data are scarce; the tectonic evolution demonstrates that these deficiencies can occur over continents from Europe to much speculation and guesswork.

Table 1.2. Evolution of the evolution of the earth during the Periods of tectonic and tectonic evolution.

Period	Time	Velocity
1	0 - 150 Ma	2 cm/y
2	150 - 400 Ma	3 cm/y
3	400 - 600 Ma	4 cm/y
4	600 - 900 Ma	1 cm/y
5	900 - 1200 Ma	3 cm/y
6	1200 - 1500 Ma	1 cm/y

After Güncör et al., 1999; Güncör et al., 1996





the same time as the extinction events indicated by the biostratigraphy; the climax of a tectonic period is always later than the end of corresponding extinctions.

For example, according to isotopic data from sedimentary carbonates in most areas of Utah, as shown in Table 1.1, 134 Ma is the most suitable age for the boundary between the Yanshanian and Eocene tectonic periods. In the international stratigraphic chart (Krause et al., 2000; International Commission on Stratigraphy, 2004), there are different opinions on the age of the boundary between the Jurassic and Cretaceous, ranging from 135 Ma to 146.2 Ma. From recent studies, most Chinese researchers accept the boundary between Jurassic and Cretaceous as either 137 Ma or 144 Ma (Li, 2000). For the age of the boundary between Jurassic and Cretaceous, the author agrees with the opinion of Li (2000), that is, the boundary between the Yanshanian and Eocene or the tectonic period lies between early and middle Eoethen of Early Cretaceous. According to (Krause et al., 2000), the age of the boundary between the Jurassic and Cretaceous for this case has not yet been reconsidered.

## 1.4 Research Principles and Methods for Interpreting Tectonic Events

### 1.4.1 The Rock Record

The study of tectonic events in the active and stable periods of tectonic evolution requires different research methods. Evidence for the active period of tectonic events is commonly preserved in the rock as structural features such as folds, faults, thrusts, joints, relations and lineaments, which may be accompanied by metamorphism as a process of metamorphism. The original changes in a rock body or in a hand specimen can be expressed in terms of the amount of deformation or strain it has undergone, i.e. reduction or expansion in volume, shortening or extension. Strain can be determined with respect to changes in the length of three mutually perpendicular principal axes of strain ( $\epsilon_1$ , maximum extension, and  $\epsilon_2$  shortest direction;  $\epsilon_3$ , intermediate;  $\epsilon_4$ , minimum compression). The largest extension  $\epsilon_1$  and  $\epsilon_2$  may be equal or have any value intermediate between  $\epsilon_1$  and  $\epsilon_2$ . Strain can be measured if the rock contains 'strain markers', objects whose original size and distribution and orientation are known and can be compared with their present size or shape (Gottschalk and Jünger, 1971).

Tectonic events may also be recorded indirectly by the tectonic sedimentation. Tectonic events are commonly accompanied by uplift and subsidence, erosion, so that the sedimentary record is disrupted. However, the tectonic events may be deposited in marginal depressions or basins or in highly deformed areas as volcanic flysch (Baltica turbidites), providing a record of episodes of uplift and erosion. Tectonic events may also be accompanied by the intrusion of magmatic rocks with synchronous alteration and associated hydrothermal metamorphism.

The study of sedimentary strata can be used to solve many problems in tectonics, such as the sedimentary facies and the sequence of formation in stable basins, for the recognition of unconformities and of episodes of strong deformation in the active tectonic period. These studies are part of a complete study of tectonics.

Methods used in the analysis of sedimentation and paleogeography are more appropriate to the stable period of a tectonic structure unit. A stable tectonic period is represented by the deposition of a continuous sequence of sedimentary strata in a tectonically stable basin. During the stable period, variations in the thickness and rates of deposition of sedimentary strata, and changes in the rate of vertical motion of the Earth's crust, such as depression or uplift, can be recognized. By determining the sequence of strata and the rates of each sedimentary unit, it is possible to place these periods of uplift and depression in a chronological sequence and to measure them. The stratigraphical methods of measuring the thickness of sedimentary strata and determining rates of deposition since the Mesozoic period is shown in Appendix 2 in a very approximate manner. There is a number of measuring methods of tectonic depression and uplift

through great thicknesses of sedimentary rocks are most likely to be the results of multiple phases of deflexion and sedimentation and uplift-erosion. Also no allowances have been made for the effects of compaction and diagenesis, or for the influence of subsidence stress caused by later tectonic events. The study of sub-sea-mechanical faults is useful to determine the history or development of sedimentary basins during a stable tectonic period. A complete calculation to the account of all these factors, however, requires an enormous amount of observational field and laboratory work.

Although a large part of sedimentary rocks, amounting to several tens of thousands kilometers, extends over the major part of the Chinese continent, the greater part of the sediment originally deposited on the continent has been eroded away and is no longer preserved. According to statistical calculations by Kooze et al. (1984, after Durr & Mial, 1976), based on the thickness and extent of sediments and the geological ages of present-day sedimentary basins, deposited since about the world at a rate of 50–100 m<sup>3</sup> per year. Mesozoic-Cenozoic sediments have been preserved on the Earth's surface, of which 50% is from the Paleozoic, 30–35% from the Proterozoic, and less than 15% from the Archean.

The accumulation of tectono-geographical data and especially the reconstruction of ecosystems are important for determining tectonic plate evolution and sub-plate crustal blocks. The reconstruction of paleogeographies demonstrates the continental tectonic block through time and supports the tectonic and concept of tectonics.

### 1.4.2 The Geometry of Rock Deformation

The foundation of the study of tectonics is the determination of the distribution and mutual relationships of rock units as seen in the field, together with their internal structural features such as folds, faults, lineations and foliations. Tectonics involves rock deformation on all scales from the megascopic to the microscopic, from the lithospheric scale to the individual mineral crystal and molecular lattice scale. It interrelates and then is integrated into a comprehensive tectonic system (Fig. 1.4.1). Tectonics is also concerned with the imprints on the evolution of igneous rocks and the metamorphism and the recrystallization of rock bodies with the formation of new minerals and new textures, and the relationship of these events to various phases of deformation. These relationships must initially be established in the field by detailed geological mapping and geological structural surveys, sample collected by drill core and by deep structural fluid inclusion geochemical methods and by the study of rocks under the optical and electron microscopes.

The deformation and the displacement of the lithosphere are the main contents of the study of tectonics. Although comprehensive methods should be used in the study of tectonics, and research should encompass all branches of the geosciences, the study of rock deformation should be made on the basis of precomparision of tectonics, which has been neglected in some recent studies.

Contributions to the knowledge and understanding of rock deformation in China during the last fifty years have been immense. It can be attributed to the exertion and success of regional geologic calssic surveys.

In addition to an omni-scale geological survey cover the whole Chinese continent, total the check of million square kilometers at the scale of 1:1,000,000, commenced, but was not completed before 1980. Regional geologic survey of regional geology at the scale of 1:200,000 was completed in the 1960s (for amphibious survey), a regional geobathymetric survey at the scale of 1:200,000 was commenced for inner areas of China before the end of the 1950s (Bureau of Geology and Mineral Resources of PRC, 1984–199). In new regional geologic calssic survey at the scale of 1:200,000 (more than 100 areas) has been completed recently over whole Qinghai-Xizang (Tibet) plateau; the results will be published shortly. These surveys raised the extent and precision of geological information substantially. A classification and comparison of regional tectonic with the description of types, scales, attitudes and the distribution of folds and faults at the macro and meso scale, and of mineralization and metamorphism built a basic foundation for studying the tectonics of China in this book.

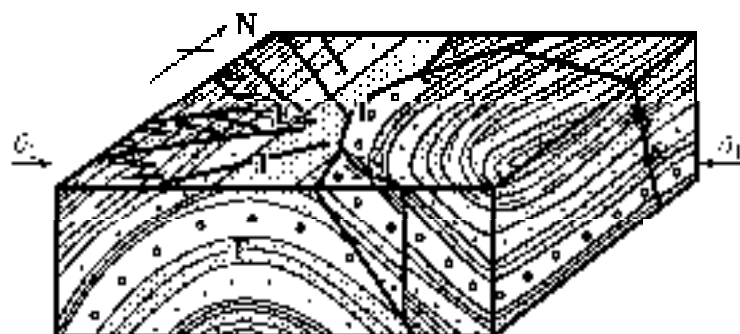


Fig. 1.5 Sketch of geological structures associated with principal stresses

$\sigma_1$ —Low angle (to regional tectonic compression and extension),  $\sigma_2$ —Horizontal stress (1.4Mbar or more), fault zone strike,  $\sigma_3$ —High angle (to extension),  $\sigma_1$ —Low angle (to extension),  $\sigma_2$ —Horizontal stress,  $\sigma_3$ —Low angle (to extension),  $\sigma_1$ —Low angle (to extension),  $\sigma_2$ —Horizontal stress,  $\sigma_3$ —Low angle (to extension).

Data concerning the geometry and attitudes of ENE/WNW and north-south folds (Fig. 10, Appendix II) have been collected and analyzed to determine regional tectonic stress orientations. In the case of the most of ENE, where detailed geological surveys on the scale of 1:200,000 have not yet been completed and detailed structural maps are not available, geological surveys on scales of 1:200,000 or 1:300,000 have been used and the strike-slip, related to anticlinal and synclinal. From these data, it can be seen that rock deformation on a widespread throughout the Chinese continent (the sphere of joint systems, the weakest type of rock deformation) can be found even in the youngest rocks throughout China, it is difficult to find an area not affected by rock deformation.

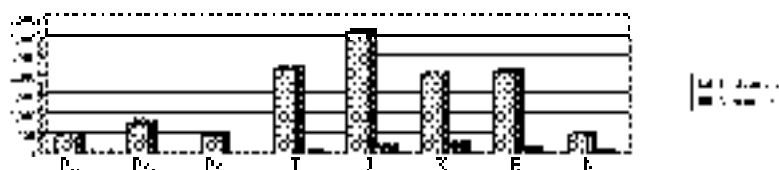


Fig. 1.6 Number of strike-slip faults in different regions: North-eastern (1:1, 150, 1:200, 1:300, 1:400, 1:500, 1:600, 1:700, 1:800, 1:900, 1:1,000, 1:1,200, 1:1,400, 1:1,600, 1:1,800, 1:2,000, 1:2,200, 1:2,400, 1:2,600, 1:2,800, 1:3,000, 1:3,200, 1:3,400, 1:3,600, 1:3,800, 1:4,000, 1:4,200, 1:4,400, 1:4,600, 1:4,800, 1:5,000, 1:5,200, 1:5,400, 1:5,600, 1:5,800, 1:6,000, 1:6,200, 1:6,400, 1:6,600, 1:6,800, 1:7,000, 1:7,200, 1:7,400, 1:7,600, 1:7,800, 1:8,000, 1:8,200, 1:8,400, 1:8,600, 1:8,800, 1:9,000, 1:9,200, 1:9,400, 1:9,600, 1:9,800, 1:10,000).

In all these areas, rock deformation is mainly linear with Alpin type folds and, in areas with high and intermediate angles of dip for the faults, associated with many thrusts. In the plate areas covering half the size of China, there is a widespread deformation with inter-plate stresses, in which the angle of dip for faults is normally less than 30°, and the folds are associated with faults. These two types of deformation are transition types, belonging to the sedimentary cover detachment type, and may be called a new type. Even in stable tectonic areas covering one-third of China, which appear to have only horizontal tectonic stress, there are linear to type folds with faults with very low angles of dip, and normal faults with high angles of dip and complex joint systems.

### 1.4.3 The Kinematics of Blocks

The aim of tectonic studies is to examine rock deformation quantitatively, with the determination of the amounts of dilation (changes in volume), contraction (changes in shape) and translation (movements of the rock body as a whole) and the orientation of the stresses responsible for the deformation (Jin, 1993). In order to obtain the determination of the rates of deformation (rates of strain) in horizontal and/or horizontal and vertical displacement, it may be necessary to manifest the effects of multiple phases of deformation, where the orientation of the stresses may have been different in each phase. This is relatively easy if the orientation of the stresses in each tectonic period was very different, but may be difficult or even impossible if these stresses were in the same, or nearly the same direction.

Research into the kinematics of the lithosphere is aimed at determining vertical movements of uplift and depression and horizontal movements of compression, extension and strike-slip movement, and the directions in which they were assumed.

Once attention has been concentrated on vertical movements of the lithosphere with the uplift and depression of Earth's surface, the determination of vertical movements during a stable tectonic period makes use of data on variations in sea level thickness, changes in lithology and facies, unconformity may also contribute to vertical movements. Vertical movements can be determined through the study of sedimentation and erosion, transgression and regression, the up rise of magma or changes in the thickness of the lithosphere over long periods of time. During the last one hundred years, while new methods were being perfected, it was seen that vertical movements were the major kinematic feature of the kinematics of the lithosphere.

This hypothesis is a kind of theoretical foundation for concepts of crustal expansion, limited plate tectonics, pan-tectonism, etc. (Vare, recently, hypotheses of one-time and closure (Yang, Wu et al., 1994, 1995; Liang, Liu, 1995, 1997), up lift of the Mesozoic (Li, disconformity) (Jin, Li et al., 1992a, 1992b, 1993, 1998), which have their bases in this earlier tectonic research, have exerted important influences over the development of tectonics in China. In these concepts, the tectonic evolution of continents takes place essentially at low, with vertical movements being the driving force for deformation and displacement, horizontal movements being secondary and limited in their extent. In these hypotheses, the importance of vertical movements has been more fully emphasized, in their accord with the possibility of near horizontal displacements over distances of several thousand kilometers. In these models, no explanation is offered at all for large-scale horizontal displacements.

The importance of horizontal deformation and displacement was much more difficult to realize, and it was not until the concept of plate tectonics (Wegener, 1924, unpublished; 1966), first proposed the Theory of Continental Drift, based on the distribution of fossils and indications of paleo-climatic zones. However, due to unexplained problems and some errors (e.g. it is impossible for the interior of continents to drift), the activities of several eminent geographers (the Geographical Institute of the USSR) after detailed discussion of the International Geological Congress in 1922, the theory of continental drift was rejected. However, Wegener's hypothesis was fundamentally correct and formed one of the foundations for the development of the theory of plate tectonics in the 1960s. This year also demonstrated the difficulty of carrying out entrenched scientific thought.

Methods for determining vertical and horizontal movements of the lithospheric plates are summarized in Table 1-3.

The kinematics of the lithospheric plates differ according to the movements of the plates: high angle normal to, reverse faults indicate vertical movements; intermediate and low angle faults indicate horizontal movements; characteristics of subduction or collisional tectonic zones and indicate horizontal tectonics; some low wrench (strike slip) faults or transform faults indicate horizontal movements of the plates; intermediate and low angle normal faults and strike-slip or transform faults are characteristics of continental rift zones and oceanic ridges and indicate the oceanic extension of the plate.

Table 14 Basic and Principles Methods for Interpreting Geomorphology

Geomorphic process	Interpretation systems
	Basement uplift causes a reduction in the change in peak elevation rate However, change in elevation rate is not linear due to the geomorphic processes
Changes of sedimentation	Horizontal movement of sedimentary facies and erosion
Termination of sedimentation in some areas (e.g., Basin-type change of plate movements)	Horizontal migration of tectonic activities Accumulation of sedimentary facies
Megathrust and subsequent uplift in a segment of the crust	Horizontal uplift of tectonic center
Extension and subsequent contraction (S-type path)	Horizontal uplift of tectonic center
Thrust faults	Uplift of the plate
Extensional faulting	Horizontal uplift and subsidence boundaries
High erosion in plateau surface with extension and subsidence faults	Horizontal uplift of tectonic

Ramsay (1997), Royden and Lister (1991) are well-known methods for determining the strain involved in fold or one unroofing, and made significant progress in this field. Yet parameters and methods for determining vertical strain fields have not yet been developed, and it is difficult to determine rates of compression and extension using conventional methods of structural geology.

Suzuki (1996) first suggested that there was a correlation in between the  $V_{\text{vol}}/V_{\text{intr}}^{\text{vol}}$  ratios of plate movement and the chemical content (K<sub>2</sub>O/Wt%, Na<sub>2</sub>O/Wt%) and silicon index ( $\text{Si} = (\text{SiO}_2 - 47.6 \times (\text{Na}_2\text{O} + \text{K}_2\text{O}) / 60.4) / 1.1$ ) of volcanic rocks near the subduction zone. In the formula above, the unit of  $V_{\text{vol}}/V_{\text{intr}}^{\text{vol}}$  is the percentage of weight, the unit of  $\text{K}_2\text{O}$ ,  $\text{Na}_2\text{O}$ ,  $\text{SiO}_2$ , and  $\text{Al}_2\text{O}_3$  are the percentage of moles (Fig. 17). Using these parameters, Suresaka (1996) discovered that the silicon index increases with increasing rates of shortening, while Nagai and Kato later used it (Fig. 17).

This relationship is not linear, yet has an exponential function. These relationships are due to the relationship of rates of silica and potassium to potassium. The rate ratios of silica are very small, while the rate ratios of potassium and sodium are relatively large. When the velocity of plate movement increases and tectonic activity is enhanced, a silica-rich rock is created, while the ions of potassium and sodium decrease relatively (Sun et al. 1982, 1999). On the assumption that the velocities of movement involved in marginal and inner plate deformation are similar, the author (Wan 1994) has used the relationship derived from the study of plate margins to quantify tectonic movements. In general, velocities of movement during inner plate deformation would be less than the rates for marginal deformation. When the velocities of plate movement for the whole of these countries are discussed, on the basis of velocities calculated from plate margins, these velocities may be slightly exaggerated. However, all the data has been treated by the same method, so that the relative magnitudes of movement velocities for different areas are acceptable.

Suzuki (1996) used only the relationship between the chemical content of volcanic rocks and the velocity of plate movement. The author has used, not only the chemical composition of volcanic rocks, but also that of intrusive rocks to estimate the velocities of plate movement, while volcanic and intrusive rocks were formed at the same time in the same tectonic series. The content of iron elements in intrusive rocks, especially NiO, Na<sub>2</sub>O, K<sub>2</sub>O, Al<sub>2</sub>O<sub>3</sub>, is much lower than that of associated volcanic rocks. Wang (1994) has made such a comparison of iron and found that the value of plate movement velocity calculated using the ratio of intrusive rocks (Chen et al. 1995, Guo et al. 1996, Li et al. 1996, Mo et al. 1997) and Wang et al. (1997, 1998) used Suresaka's method to estimate velocities of extension and compression of blocks in the Cenozoic volcanic areas of eastern China and of the Late Cenozoic volcanics in the Hengduanshan area. Using this method the



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